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## Benefits of Highly Predictable Flight Trajectories in Performing Routine Optimized Profile Descents: Current and Recommended Research

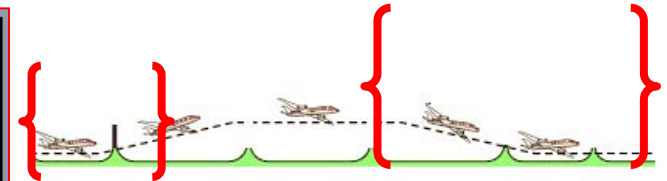
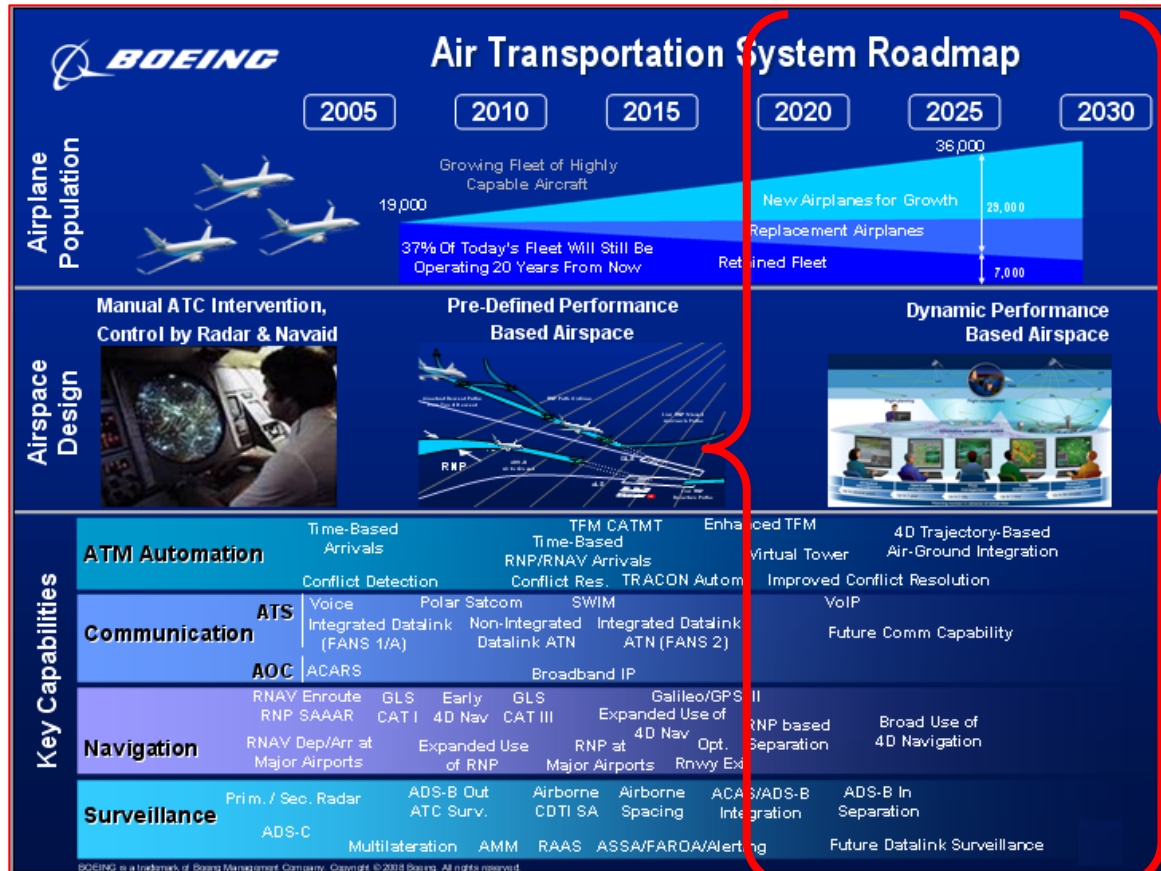
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# (BR&T) Human System Integration ATM Research Focus

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Human Systems Integrations



A principal research focus of BR&T Human System Integration (HSI) is Super Density Operations in the far-term time horizon, with specific emphasis on environmentally beneficial procedures

# (BR&T) Human System Integration ATM Research Focus

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## Problem Area

### Global Research Areas

- Advanced Super Density Operations (SDO) arrival concepts with emphasis on Continuous Descent Arrival (CDA)
- Transition options from current-day SDO 3D Performance-Based Navigation (PBN) to 4D Trajectory-Based Operations (TBO)

### Select Boeing Research & Technology (BRT) SDO Research Topics

- Efficiency and practicality of BRT-developed CDA-Maximum Predictability (CDA-MP)
- Comparative evaluations of specific CDA concepts
- Effects of operational disruptions on ATM (e.g., weather avoidance, flow direction change, runway capacity reduction)
- Potential, future roles and responsibilities for pilots and controllers

## ATM System Predictability vs. Flexibility

- “Descend Via” Clearances
- Types of Descents
  - Pilot Technique and Training
  - Optimized Profile Descents

# (BR&T) Human System Integration ATM Research Motivation

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ASRS #	A/P	A/C	SUMMARY
785150	DCA	A320	AN A320 REPORTS CROSSING THE REVUE WAYPOINT ON THE DCA ELDEE ARR LOW. THE WORKLOAD IS HIGH AND THE NUMBER OF CHANGES TO THE ARRIVAL CONFUSING.
785354	DCA	B757	A B757 CAPT REPORTS CROSSING THE REVUE WAYPOINT ON THE DCA ELDEE ARR LOW. NOTAM CHANGES ADDED TO CONFUSION ABOUT PROPER CROSSING ALTS.
776259	ATL	B757	THE ARRIVAL PROCEDURE WAS CHANGED AS A B757 FLT CREW WAS APPROACHING ATL. WHEN THE NEW STAR WAS SELECTED, THE ALT RESTRICTIONS WERE NOT IN THE FMS, AND THE FLT CREW OVERSHOT THE RESTRICTIONS
779546	LAX	B777	B777 FLT CREW IS ASSIGNED RIIVR1 ARRIVAL TO LAX WITHOUT RWY. FLC ASSUMES RWY 24R INCORRECTLY AND IS VECTORED FOR VISUAL TO RWY 25L. DESCENT IS STOPPED BY SCT AT 9000 FT.
777213	SLC	B737	A B737 PILOT COMMENTS THAT DURING A SLC FMS RNAV ARR RWY CHANGE WAYPOINTS WITH ALT CONSTRAINTS WERE DROPPED THAT MUST BE FLOWN USING AUTOMATION. AN ALT CONSTRAINT WAS MISSED AND ACFT DSNDED EARLY.
745026	LAX	B737	A B737-700 GETS A RUNWAY CHANGE APPROACHING LAX AND FAILS TO MAKE A CROSSING RESTRICTION
745756	PHX	B737	A B737-300 FLT CREW MISSES CROSSING RESTRICTION AT EDDNA ON MAIER RNAV STAR TO PHX. MULTIPLE CHANGES IN RWY ASSIGNMENT REQUIRED REPEATED REPROGRAMMING OF THE FMS AND REMOVED THE PNF FROM ACTIVE MONITORING OF THE ACFTS FLT PATH.
745723	LAX	A320	APCH CONTROL DIRECTED RWY CHANGE FOR A320 ON CIVET ARRIVAL TO LAX RESULTS IN LOSS OF MAP DISPLAY AND CONSEQUENT TRACK DEVIATION DURING REPROGRAMMING OF FMS.
738305	LAX	B757	B757 CREW INTERCEPTS RWY 25L LOCALIZER AS THEY BELIEVE THEY WERE CLRED, SCT CTLR ISSUES VECTOR TO INTERCEPT THE RWY 24R LOCALIZER AS HE BELIEVES THEY WERE CLRED.
739109	PDX	B737	B737 CREW MISSES CONDITIONAL CROSSING RESTR AT BONVL ON THE BONVL 5 ARR INTO PDX AFTER RWY CHANGE.
733004	LAX	B757	B757 FLT CREW HAS A CLOSE-IN RWY CHANGE DURING CIVET 5 ARR TO LAX
727984	LAS	737	B737-700 FLT CREW MISSES CROSSING RESTRICTION DURING ARR TO LAS.
729124	SEA	B737	B737-300 CREW MISSES CROSSING RESTR AT RADDY ON THE CHINS 5 ARR TO SEA.
722932	LAX	B737	B737-700 FLT CREW HAS A CLOSE-IN RWY CHANGE ISSUED ON THE SEAVU ONE ARR TO LAX.
724615	LAX		CR CREW ENCOUNTERS DIFFICULTIES CHANGING RWYS DURING THE SEAVU1 ARR INTO LAX.
719407	LAX	B757	B757 CREW MISSED CROSSING RESTR ON CIVET 5 AT LAX AFTER RWY CHANGE.
722352	LAX	B737	B737-700 FLT CREW HAS TRACK/HEADING DEVIATION DURING SEAVU ONE ARR TO LAX.
717557	PHX	B737	B737 CREW DESCENDS EARLY APCHING QUENY ON THE EAGUL 1 INTO PHX DUE TO NAV PROB.

Also see: Barhydt, R. and. Adam, C. Human Factors Considerations for Performance-Based Navigation, NASA Langley Research Center, NASA/TM—2006–214531, December, 2006

# (BR&T) Human System Integration ATM Research Focus

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## “4D” Trajectory Based Operations

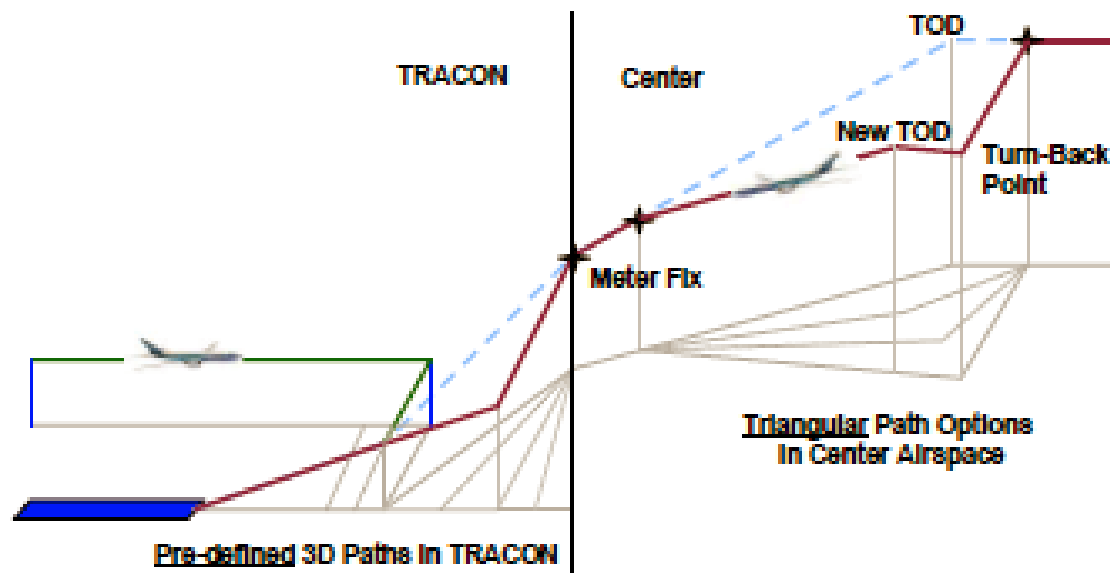
- “4D” State of the Art Procedures
- 4D System Level Goals
- Capability Gaps
- Research Domains to close capability gaps

# “4D” TBO State of the Art– 3D PAM

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*Existing technology and procedures allow for short-term/mid-term preliminary “4D” TBOs – these provide benefits compared with current operations*

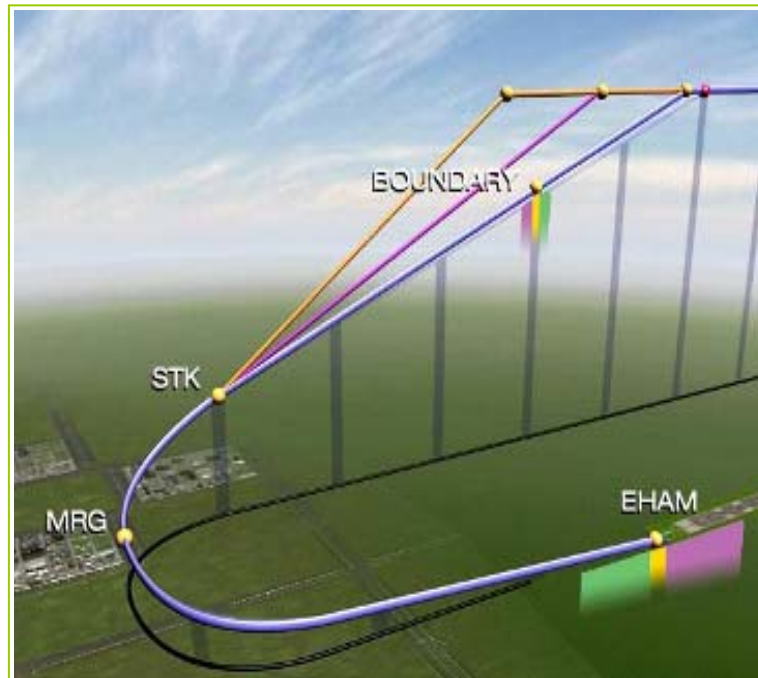


- FMS uses reliable and efficient routing to deliver aircraft from the Top of Descent to the metering fix
- The 3D PAM concept is a near to mid-term step towards NextGen 4D trajectory operations
- Improves accuracy of meter fix delivery, reduced delays and number and duration of voice communications

# “4D” TBO State of the Art– Tailored Arrivals

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- Procedure used on oceanic arrivals with aircraft equipped with integrated Future Air Navigation System (FANS) 1/A equipment
- Pre-planned RNAV routes are data-linked to the aircraft before Top of Descent
- Trajectory is optimized vertically and laterally



# Far-term 4D TBO System Level Goals

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## Commonly Agreed Benefits of 4D TBO to Support SDO Objectives

- Higher efficiency and less environmental impact thru shorter lateral paths, optimized vertical climb and descent profiles, and WP RTAs
- More economical operation thru lower fuel usage and lower throttle activity
- High arrival and departure throughput thru runway balancing, predictable longitudinal, lateral and vertical spacing
- Same or improved safety

# ***Needs for Transitioning Short/Mid Term Solutions into Future 4D TBO***

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## Means to Increase throughput and Optimize Conflict Avoidance

- More predictable current and future aircraft trajectories  
Ability to assign 4D TBO clearance(s) to each aircraft that specifies a highly-precise standard for the aircraft's 4D position throughout the flight
- Enhanced air/ground synchronization  
Need to identify what information has to be down linked by the aircraft to enable the ground-based automation to synchronize its prediction with the airborne one in order to reduce separations and delays and facilitate “what if” modifications of the predicted trajectory

# Capability Gaps in Transitioning Mid- Term Solutions to Far-Term 4D TBO

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- Current traffic sequencing and separation are limited by the uncertainty inherent in determining an aircraft's current position and forecasting its future 4D positions

*(Aircraft and ATM have not reaped the full benefits of GPS/GBAS)*

- Required Time of Arrival (RTA) is based on control logic to meet target, not necessarily showing adherence to contracted 4D trajectory along the descent
- Future 4D TBOs are to feature higher levels of integrity and navigation accuracy, optimized traffic management supporting automation, improved Human System Integration and advanced operational concepts

# Capability Gaps in Transitioning Mid- Term Solutions to Far-Term 4D TBO

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Operational Factor	Limitation
<b>System Flexibility</b>	P/C have less control of descent speed (a/c will compute the right speed to hit the RTA); All RTA functions are given a limited range of authority to change speed; aircraft chooses between adhering to a time constraint (to meet RTA) or a speed constraint (if aircraft cannot fly speed required to meet RTA)
<b>Mixed Equipage</b>	B737 NG FMC and some recent FMCs have RTA functionality during descent; otherwise, RTA is not managed after TOD in most A/C. Only one RTA WPT at a time can be set in FMS
<b>Efficiency</b>	“Continuous RTA” profile may result in excessive throttle activity to adjust speed
<b>Commonality</b>	Not all aircraft work the same with respect to use of RTA - controllers cannot simply uplink a time to an airplane and expect it to be able to achieve that time
<b>Winds</b>	The way the RTA algorithm is implemented, accurate forecast winds are essential for use of RTA over an extended time

# Research Domains for Far-Term 4D TBO (Integrated Solution)

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- Dynamic Performance-Based Navigation
  - Advanced Guidance Algorithms
  - Advanced Ground Automation
  - Overall System Integrity (how does the system know that a/c are compliant with contracted trajectories)
- Operational Considerations/ Operational Concept
  - What level of trajectory predictability (control) is needed by the ANSP to achieve NextGen/SESAR objectives
  - How does trajectory predictability trade-off with system flexibility
  - What is the nature of the trajectory exchange between aircraft and ground
  - What are the new Procedures and Standards for Airspace Design
- HSI Considerations
  - Roles and Responsibilities
  - Function Allocation
  - Workload
  - Interface Design
  - Safety

# Ongoing research on 4D guidance methods

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Method	Description
<i>Discrete 4D Guidance (RTA)</i>	RTA logic applied to several waypoints during descent
<i>Discrete and Continuous 4D Guidance</i>	Path-on-elevator + groundspeed-on-throttles or speed brakes (nominal idle thrust)
<i>Continuous 4D Guidance</i>	Method based on ground speed on elevator control
<i>Discrete 4D Guidance (RTA)</i>	4D trajectory is re-negotiated with ground during the descent
<i>Continuous 4D Guidance</i>	Groundspeed-on-elevator + vertical deviation containment using throttles (nominal off-idle thrust)

*Conduct Monte-Carlo Fast Time Simulation in realistic conditions to assess:*

- *Throttle activity*
- *Navigation performance (vertical and along track)*
- *Fuel usage*

# Research Domain – Concept Development and Evaluation

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**The ATM systems issue conflict-free 4D trajectories that are flown by equipped aircraft**

**The ATM system calculates the 4D trajectories for each aircraft that are:**

- **Compatible with, and based on, aircraft performance where the ATM system has database of aircraft types and associated performance that include the effects of aircraft weight, altitude, and temperature**
- **Consistent, as much as possible, with user-preferred trajectory requests**
- **Fair distributing penalties among the system users (to ensure separation)**
- **Aimed at minimum time enroute, fuel, and emissions**

**With precise knowledge, ATM decision aids can be used to establish sequencing, merging, and spacing on a strategic timescale, as well as a tactical timescale and supporting “control by exception”**

# Research Domain – Human System Integration Considerations

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## Roles and Responsibilities

- In-Trail Procedures
- TBD role in separation assurance

## Function Allocation

- Role of automation
- Override and trajectory modification

## Workload

- Assessment

## Interface Design- Flight Deck

- FMS CDU, MCP, ND, PFD
- Message content

## Interface Design – Ground Systems

- Controller Projections of Traffic
- Trajectory Constraints and Tolerances



# Dynamic Performance-Based Navigation Advanced Guidance Algorithms

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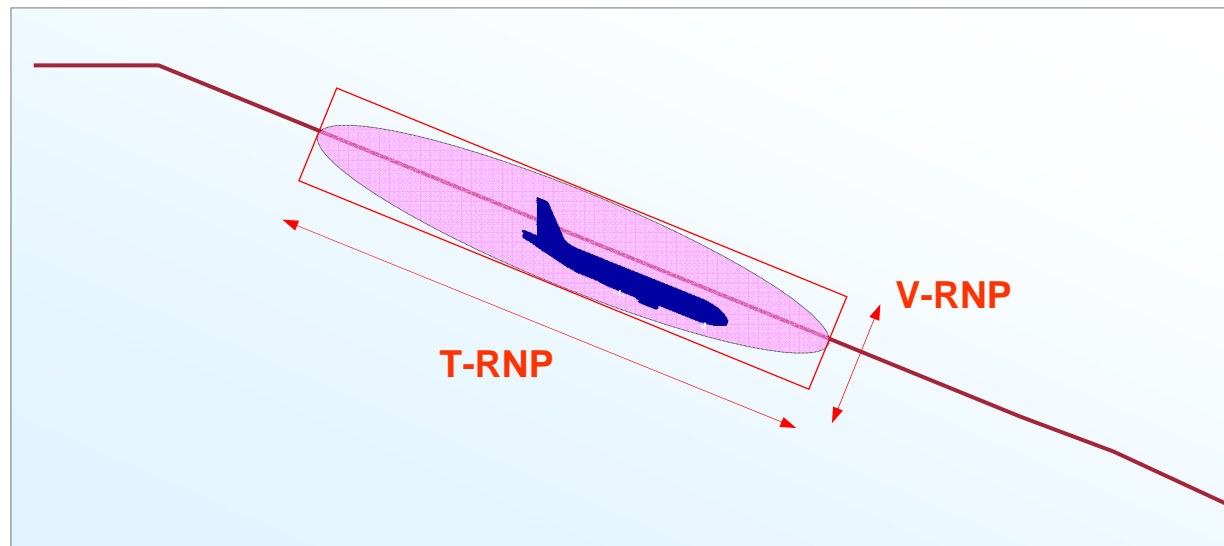
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**BR&TE Advanced Navigation Logic**  
**Continuous Decent Arrival- Maximum Predictability (CDA-MP)**

# 4D Trajectory as Key Element for NextGen and SESAR

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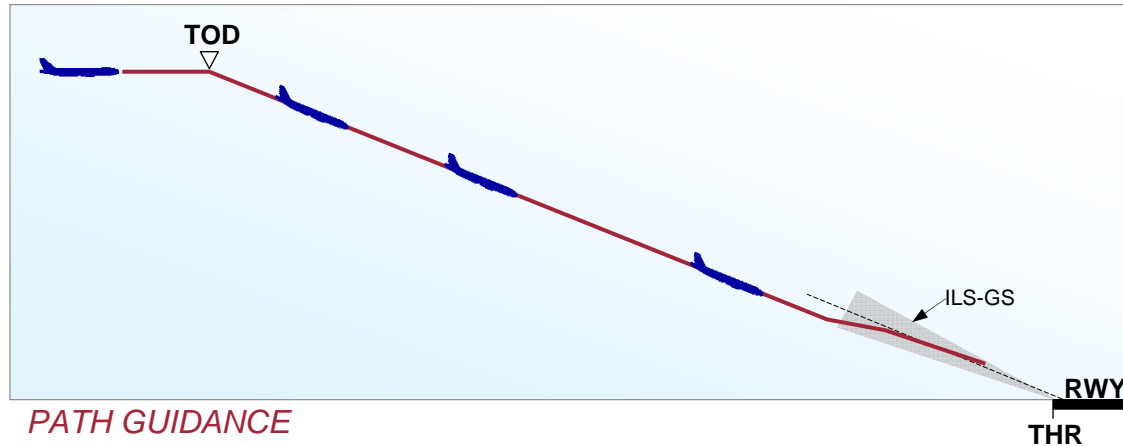
## ***Agreed Benefits of Continuous 4D Navigation***

- It ensures compliance with “contract” negotiated 4D trajectories (Ballin, Williams et. al, DASC 2008)
- Redundant integrity systems are straightforward, onboard and/or on the ground side, in order to verify 4DT compliance
- System integrity is fundamental to ensure safety of operation

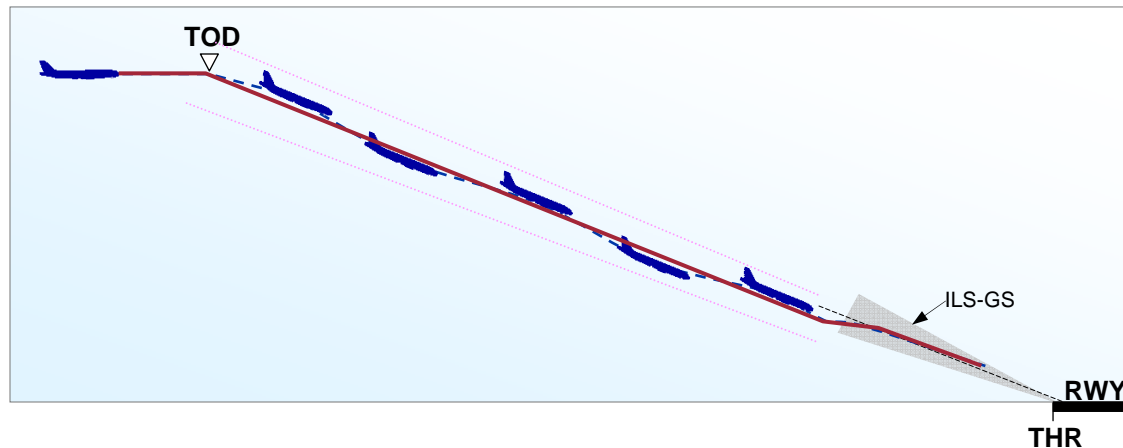
# Path-Constrained Guidance versus Other Methods

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- Most open-loop or RTA approaches
- Widely accepted method.
- **IDENTIFIED PROBLEM: continuous 4D guidance -> excessive throttle activity.**



- TECS-based 4D guidance
- PHARE
- DLR
- NASA 4D FMS (via recalculation of path).
- BRTE's CDA-MP

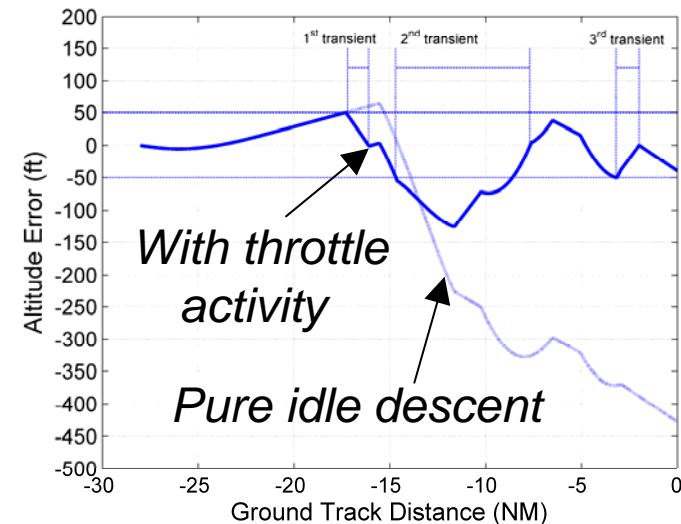
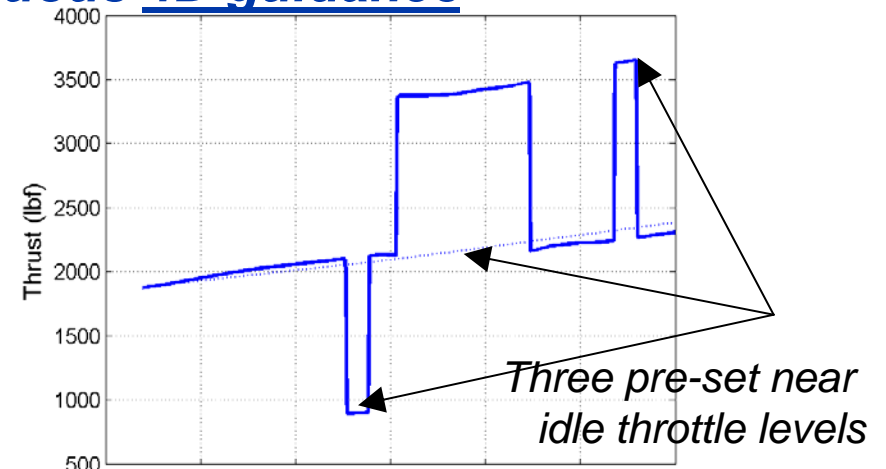
# Novel CDA-MP 4D Guidance Method

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Combined system of **groundspeed on elevator plus thrust corrections: continuous 4D guidance**

- **Groundspeed control**
  - Time errors <  $\pm 3$  seconds throughout the descent (99.73% confidence)
- **Throttle activity**
  - **When vertical deviation reaches given thresholds** (say  $\pm 100$  feet). throttles are temporarily set to another near-idle value.
  - Effective vertical deviation containment.
  - **Engine remains stationary most of the time**



# Key Ideas about the CDA-MP 4D Guidance

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- Can make use of **currently existing autopilot modes** to achieve time guidance. Agile and efficient elevator control.
- **Occasional thrust corrections** for vertical deviation containment within V-RNP. Efficient engine use to **avoid unnecessary throttle transients**.
- Can make use of currently existing lateral guidance.
- Provides **continuous 4D Trajectory management** and enables independent integrity systems to verify compliance

# CDA-MP Flight Deck Design with today's Auto Flight / Flight Management System

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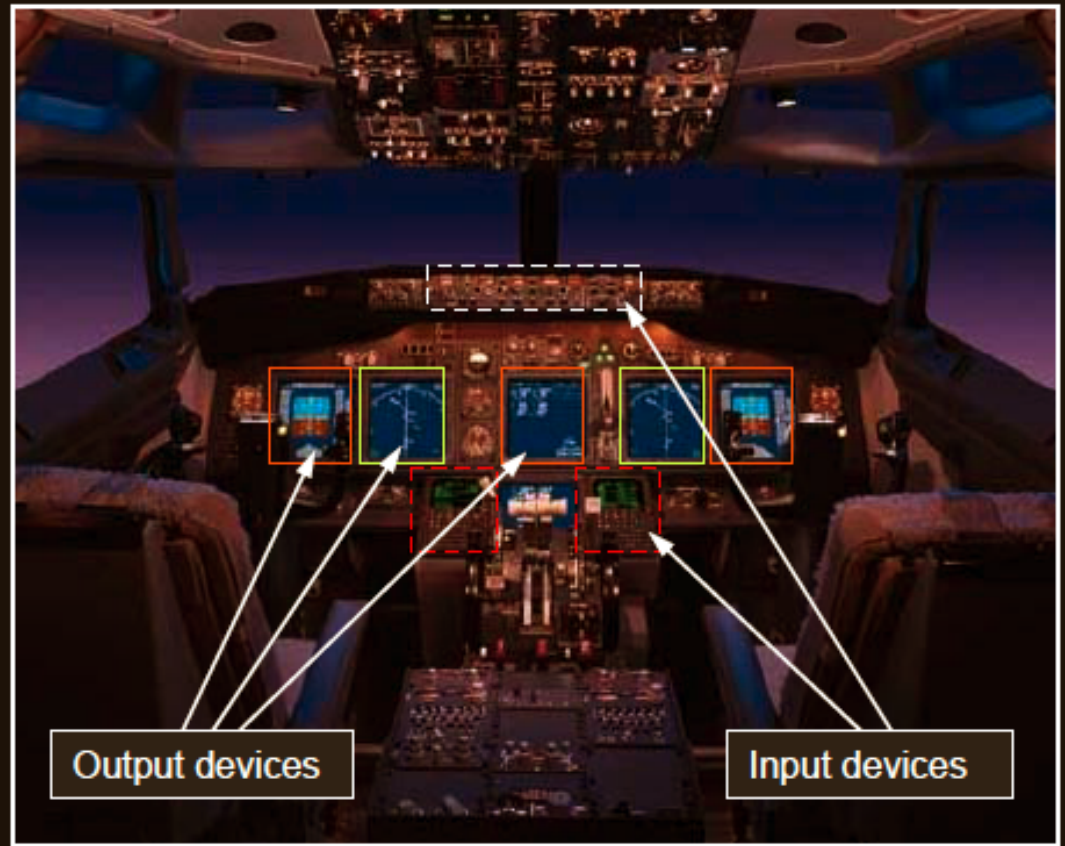
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MCDU – Management / Monitoring

PFD / Upper DU –  
Mode Awareness / FD & THR CMDS

ND – Performance Monitoring

MCP – Intervention

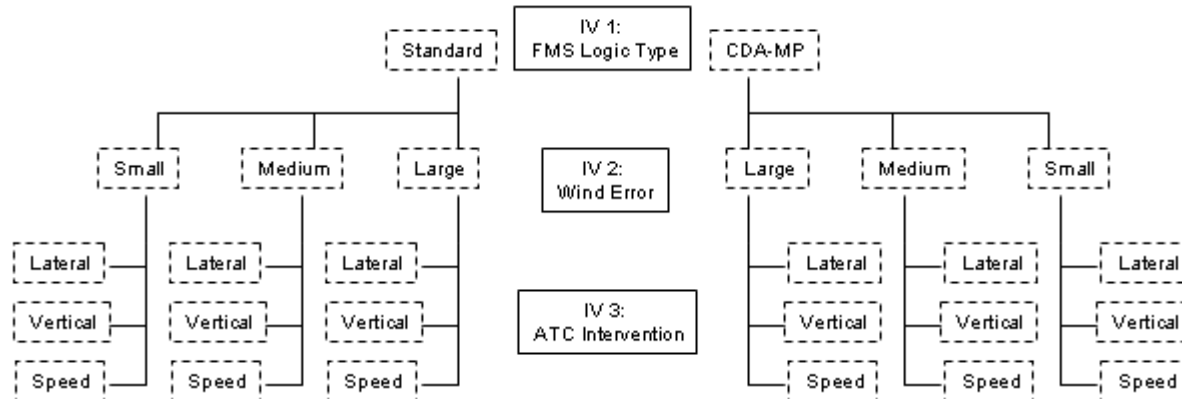


# CDA-MP Simulation Plan (2010)

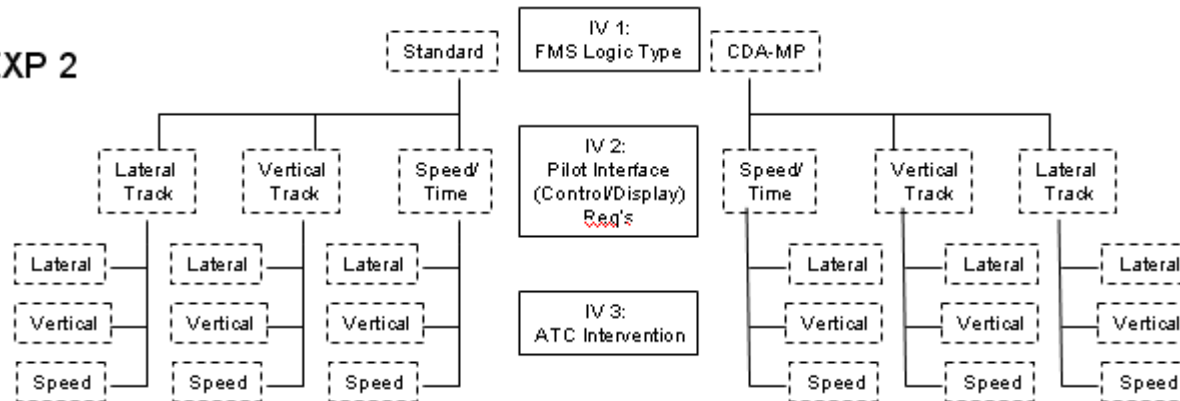
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## EXP 1



## EXP 2



**Research Objective:** Compare the operational practicality of CDA-Maximum Predictability (MP) flight procedures to standard CDA flight procedures in satisfying safety, Federal Aviation Regulations, pilot performance capability, and pilot acceptability. Additionally, compare the effects of air traffic control (ATC) clearances that temporarily interrupt execution of the CDA-MP/Standard CDA procedures.

# Super Density Operations Proposed Future Research

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**Scope & Vision:** Collaborate with research community for ATM modernization; pursue globally interoperable solutions; create differentiating concepts for the Flight Deck and Ground Systems to achieve NextGen goals for capacity, efficiency and safety – with a focus on procedures designed for environmental benefit

**Metrics:** Airport Capacity, % a/c kept on OPD, controller and pilot workload, reduced noise and emissions, fuel efficiency

**Approach:** Use common fast-time simulation toolset (FACT, APATS & SAM,TAME) to assess alternative solutions; develop flight deck & ground automation layouts; Use human-in-the-loop simulations to assess operator acceptance and refine assessments of alternative solutions

**Benefits:** Increased use of OPD in busy terminal area with projected increased capacity

**Concept Trades:** Energy management advanced guidance logic vs RTA to final scheduling point

**Human Factors Considerations:** Roles and Responsibilities, Usability, Automation, Workload, Situation Awareness

**Deliverables:** Fast-time simulation results, Control/Display Design Options, H-I-T-L results, Operational Concept Description, Initial assessment report on certification and flight standards issues

**Milestones Supported:** (AS.1.6.04) Explore innovative guidance and control methods for the super density terminal environment; (AS.4.6.01) ASDO final ASDO final concept of operations for automated, mixed operations in metroplex environment

**Customer Opportunity Values:** Reduced Community Noise; Increased Capacity